1982

Optimal soil management over time

Michael James Monson
Iowa State University

Optimal soil management over time

by

Michael James Monson

A Thesis Submitted to the

Graduate Faculty in Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

Department: Economics

Major: Agricultural Economics

Signatures have been redacted for privacy

Signatures have been redacted for privacy

Iowa State University
Ames, Iowa

1982

TABLE OF CONTENTS

ABSTRACT

The potential effects of soil loss on crop production are discussed and a rationalization of why these costs are not considered in producer decisions is developed. Where empirical data is available, these onsite costs are quantitatively estimated and incorporated in a dynamic linear programming model of a small Iowa watershed. A loss in crops and acres is linked with annual soil loss to represent gully erosion in the model. Other potential onsite costs are estimated by a fixed cost per ton of soil loss. This fixed charge is analyzed at several levels. The sensitivity of soil depletion to these various costs is determined by the model solutions. The results indicate that relatively small costs of erosion significantly reduce the amount of soil lost over time. While no conclusions can be drawn as to whether these onsite costs are considered by the producer, the analysis shows that knowledge and consideration of these onsite costs can cause a major reduction in soil erosion and changes in crop management practices over time.

ACKNOWLEDGMENTS

I would like to express my gratitude to Dr. John Miranowski for his wisdom, guidance, and patience in the writing of this paper, and for providing me with the opportunity to develop my interest in research at Iowa State University. Thanks also go to the members of my committee, Dr. Frederick Troeh and Dr. John Timmons. Dr. Troeh provided excellent background for my paper in his soil and water conservation class. Also, Dr. James Shortle of Pennsylvania State University was instrumental in the construction of the model. The work of my sister, Kendra Stumpenhorst, in typing this paper surely means her name well deserves to be included in this thesis.

Finally, thanks to my friends, especially one, for the motivation to complete my work at Iowa State. Their tolerance of a tired associate was greatly appreciated.

CHAPTER I. INTRODUCTION

History

From the first civilizations dependent on agriculture, the loss of soil and its productive capacity has plagued mankind. Troeh et al. (50) cites the Mesopotamian empire, which at its peak sustained a population of twenty-five million. In the 1930s, Iraq, the major representative of this ancient civilization in the modern world, had a population of only four million. Erratic river flow and sediment deposition resulting from upland erosion destroyed the irrigation systems that were needed to make the lowland soils productive. Evidence of past erosion remains today in the badly gullied uplands where much of the original soil is gone. Soil was valued so highly by the Inca Indians of South America that they constructed elaborate terrace and irrigation systems by hand. Other civilizations were not as careful. Lowdermilk (30) links the downfall of eleven empires with the impacts of soil erosion.

Soil erosion was of little concern during much of the history of the United States. Where land had been cultivated with enough intensity to deplete its productive capacity, farmers simply moved on to new soils in the unsettled frontier. The level of public attention given to soil loss was minimal until the 1930s. Dust storms in the drought-stricken Great Plains states clouded the skies and deposited soil particles all the way to the East Coast. Vast expanses were stripped of productive topsoil. Farm families from the devastated areas underwent severe hardships as they were forced to relocate. The dramatic effects of the Dust Bowl in this era prompted legislation to deal with the problems of soil erosion.

Fortunately, the United States has been spared such dramatic and sudden occurrences of soil loss since the Dust Bowl. However, the soil base has been gradually depleted, despite technological advances that have increased productivity and the agricultural land base. In fact, many of these advances may have increased the rate of depletion. In a paper given at the 1978 meeting of the American Association of Agricultural Economists, Oscar Burt (9) observed that ". . . the economics of soil conservation has been a neglected subject in agricultural economics during the last two or three decades. The most obvious reason for this apparent lack of interest in the subject is the view that advances in technology have made soil resource per se of less consequence for agricultural production." This concern becomes more relevant as the rate of depletion increases to meet the pressures of a growing population and rising standards of living.

Technological Changes

The switch from "horse power" to "horsepower" as tractors replaced draft animals had tremendous impacts on the amount of pressure that could be placed on the soil stocks. Pasture and less-erosive forage crops were no longer required to feed horses and mules. The adoption of the tractor freed areas previously set aside for these crops to be used for the production of more profitable and unfortunately more erosive row crops.

The labor-saving advantage of the tractor over draft animals increased the acres the individual farmer could devote to row crops in the production period. One could till and plant only a limited number of acres with animals. Even with the increase in farm size, the acres that today's farmer can devote to row crops is unlikely to be constrained by labor requirements. Increases in tractor power increased the intensity of tillage. The farmer can perform more tillage operations during a season and reach deeper into the topsoil. A wide variety of tillage equipment has been developed, but only recently has machinery technology focused on soil conservation.

Technological advances have made long-term crop rotations less important in modern agriculture. Rotations as a means of maintaining or improving soil fertility are not necessary as long as chemical fertilizers are readily available and relatively cheap. The use of pesticides to control weeds and insects permits monocultural and limited rotational cropping practices. The forage crops in long-term rotations are not as valuable as a feed source for draft animals. As the protective cover provided by pasture and forage crops in these rotations are replaced by row crops, erosion of the soil base increases.

While fertilization increases crop cover and crop residues, aiding in the reduction of erosion, fertilizers can also be used to increase yields, at least temporarily, on marginal land where natural soil fertility would not provide enough nutrients for profitable yield levels. Higher-yielding crop varieties coupled with fertilizer applications provide incentive for crop production on fragile lands. Machinery and other fixed costs can be distributed over more acres, reducing the average cost per unit of production.

The technological advances and capital investments that have increased the productive land base within the geographical boundaries of the United States have made the conservation of soil seem less important. Innovations in soil conservation practices and structures lead to crop production on soils where the erosion hazard of conventional farming practices limit its use. Coupled with the factors that have increased soil productivity, these marginal lands may now be farmed profitably even with the additional cost of a soil-conserving practice or structure. Drainage projects in the Midwest convert swamps and marshes into some of the most productive farmland in the world. Irrigation in the West converts drylands into valuable production areas. Wildlife habitat and recreational areas may be lost. Erosion may increase as native crops are replaced by more erosive crops. Physical, technical, and economic constraints limit how much these conversions add to the productive soil stock.

Conservation Motives

The economic pressures on the soil base have changed dramatically since the 1930s. Following World War I, the United States was burdened with surplus production of many crops. Depressed commodity prices led to many farm foreclosures and bankruptcies in the agricultural sector before and during the Great Depression. Except for a brief period during World War II, surplus production was the main problem in United States agriculture until the 1970s.

An examination of governmental policy in the 1930s shows that soil conservation was mainly a side-effect of controlling surplus production. When the Agricultural Adjustment Act of 1933, which provided direct cash benefits to farmers, was stricken down by the Supreme Court, Congress responded with the Soil Conservation and Domestic Allotment Act of 1936. While this act provided partial payment for most soil conservation practices and structures, particularly encouraged were those practices that reduced surplus crops, such as "set-aside", "idle" acres or "land banks", some portion of the farm was eligible for payments if acres of surplus crops were reduced.

The concern for environmental quality that developed in the late 1960s brought a new emphasis to soil conservation. While there are some instances of point source water pollution from agriculture, crop production activities generally result in nonpoint source pollution. Nonpoint sources have been shown to account for over half of all pollutants entering the nation's waterways in recent years (U.S. General Accounting Office, 58). It was noted in the same study that unless nonpoint sources are brought under control, the 1983 "fishable and swimmable" water quality standards set forth by Congress in the 1972 Federal Water Pollution Control Act Amendments will be unachievable. In terms of volume, sediment is by far the major nonpoint source pollutant and sediment from cropland accounts for 40% of the total sediment flow (U.S. General Accounting Office, 58). Unfortunately, sediment also serves as the primary transport mechanism for many of the agricultural chemicals that may be potential pollutants. It remains, as Crosson and Brubaker (13) argue persuasively based upon a review of available data and literature, that the major threat to water quality in the nation from agricultural production arises from soil erosion and sedimentation.

Under Section 208 of the Federal Water Pollution Control Act Amendments of 1972, the Environmental Protection Agency delegated nearly all planning and control of nonpoint source pollution to the states, subject to EPA approval. States were required to identify agriculturally and silviculturally related nonpoint sources of pollution and to devise procedures and methods by which to control such sources. Amendments in 1977 to Section 208 promoted the installation of "best management practices" (BMPs) to control water pollution from nonpoint sources. The program provides technical and financial assistance on a cost-sharing basis for those practices that improve water quality and are consistent with the areawide waste treatment management plans devised by states under Section 208. The emphasis of 208 planning has been upon those BMPs which can be adopted by farmers to control erosion and runoff and inhibit sediment delivery. In practice, 208 programs have to some extent become extensions of existing soil conservation programs.

Improved environmental quality and soil loss control were in conflict with farm export promotion effort to offset United States oil imports. Thus, fencerow-to-fencerow crop production was encouraged. By 1980 nearly forty percent of the agricultural production of the United States was marketed overseas. The burden placed on the productive soil in this country has been tremendous. Thus, soil erosion has become a concern in terms of the long-run affects on productivity, and ultimately the future food supply.

Objectives

Farming is undertaken to create a more favorable environment to increase the flows of harvestable goods and services from the land (Shulze, 42). While enhancing given flows is a beneficial outcome of these modifications, there may also be adverse consequences in the form of impaired flows of other goods and services of a temporary or permanent nature. One such consequence is the acceleration of soil loss.

The consequences of soil loss can be divided into offsite costs, such as sedimentation of reservoirs, increased flooding, and habitat loss, and onsite costs, such as reduced productivity, higher production costs, and declining value of the soil stock. Recent studies have been directed at nonpoint source pollution control and focus on erosion control for water quality improvement. These include studies of farm level impacts (Boggess et al., 5; Boggess et al., 6; McGrann, 31); watershed and riverbasin level impacts (Alt and Heady, 2; Miranowski et al., 33); regional impacts, particularly in the Corn Belt (Taylor and Frohberg, 49; U.S. Department of Agriculture, 53); and national impact studies (Crosson and Brubaker, 13; Wade and Heady, 61). These studies focus on the effects of alternative public policy for controlling soil erosion, pesticide and fertilizer usage, crop and livestock production, and farm prices and income within the framework of static linear programming models. The failure to incorporate the effect of erosion's onsite costs on the private decision-maker's use of the soil may result in misleading information about the effectiveness of policy measures on agricultural production. Static linear programming models ignore the future effects of soil erosion and thus any onsite or private benefits arising from soil erosion control.

Onsite costs of soil erosion have been incorporated in this change as well to a limited extent, focusing primarily on productivity losses (Harmon et al., 19; Burt, 9; Frohberg and Swanson, 18). Other onsite costs have been difficult to quantify. Rausser calls for partial analysis focusing on the important soil resource variables systematically through time, noting many of these relationships have been ignored in the management of soils. Ignorance of these costs by the private decisionmaker may result in a nonoptimal use of the soil resource. Consideration of these costs may lead to less environmental damage reducing the need for and cost of public policy to achieve soil erosion control.

The remainder of the paper is devoted to an empirical analysis of soil erosion and the incorporation of onsite cost estimates in a dynamic profit-maximizing model of the Four Mile Creek watershed in Tama County, Iowa. The purpose of this analysis is to determine the effect of the incorporation of onsite costs in the producer's decision-making process by evaluating the selection of management practices that achieve an optimal rate of soil use over time. A detailed description of how these costs are incorporated in the analysis is provided in Chapter III. The Four Mile Creek area has been selected because it is small enough (12780 acres) to allow a relatively detailed analysis and has a set of soils with a range of erosion problems providing a variety of onsite costs. The predominant land use in the area is agricultural, with corn and soybeans as the principal crops. A detailed description of the study area is available in Miranowski et al. (33).

CHAPTER II. DEVELOPMENT OF THE PROBLEM

Objectives

The existence of offsite costs imposed by soil erosion has been well-documented in recent years owing mainly to renewed environmental concerns (Alt, 1; Lee, 27; Swanson, 48; U.S. Department of Agriculture, 53). Lower water quality, increased flooding attributed to reservoirs with diminished capacity, and chemical pollution transported with sediment are just some of these offsite costs. The farmer's concern with these costs is limited to the share he must bear as a member of the general public. Since this share is quite small, so generally are his efforts towards controlling these offsite impacts of soil loss.

The farmer's greater concerns about soil loss are the costs he must bear directly as soil loss affects the profitability and value of his farming operation. These costs are often dynamic in nature; erosion in one period affects subsequent periods as well. An extensive dynamic theoretical model of optimal soil loss incorporating onsite and offsite costs has been developed by Shortle (43). Stated simply, the view of soil as a natural resource for the producer implies its use over time to generate returns to the farmer. The question relevant to the producer is the level of soil use that gives the greatest value of his use. In terms of onsite costs, the use of the soil in early periods may result in decreased profitability and value in later periods. Ignoring the costs of soil use in later periods results in a lower net present value for the soil resource.

Shortle's empirical analysis included only productivity impacts of soil use. Productivity losses from soil erosion have been examined in many studies throughout the country (Alt, 1; Frohberg and Swanson, 18; Harmon et al., 19; Seitz et al., 41). However, productivity losses are not the only costs imposed on the farmer by soil erosion. It is the purpose of this study to elaborate on these other costs, include them in the producer's decision making process, and evaluate their potential effect on the optimal rate of soil depletion relevant to the producer.

The Soil Loss Mechanism

To better determine the possible onsite impacts of soil loss, one must be familiar with the mechanisms of soil erosion and its manifestations on the farm. The discussion is confined to erosion by water, as quantitative measurements of soil lost to wind erosion are not as well-defined for the study area. The amount of soil lost to wind erosion and its effects on onsite costs in the study area are assumed to be negligible.

Water erosion removes soil from farmland in three major forms: sheet, rill, and gully erosion (Troeh et al., 50). Sheet erosion removes topsoil in thin layers over the entire soil surface. Raindrops detach soil particles and surface flow serves as the transportation mechanism. Rill erosion leaves small channels (rills) as runoff water concentrates in small streams when flowing downhill. The channels left by rill erosion are small enough to be smoothed by normal tillage operations, so that the long-term effect of rill erosion is similar to sheet erosion. Gully erosion leaves channels too large to be erased by normal tillage operations. Gully erosion presents an immediate problem in that the surface where the gully formed can no longer be farmed without extensive and expensive earth-moving and steps must be taken to halt further expansion. The impacts of sheet and rill erosion are discussed jointly while the particular problems of gully erosion are discussed separately.

Sheet and rill erosion can be predicted with the Universal Soil Loss Equation (USLE) Developed by Wischmeir and Smith (63). This equation predicts the amount of soil detached and transported within a field on the average over a year. Erosion levels in the watershed predicted by this equation range from zero to over two hundred tons per acre with conventional cropping practices. The equation is:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where: A = Average gross soil loss (tons per acre);
R = Rainfall-and runoff factor;
K = Soil-erodibility factor;
L = Slope-length factor;
S = Slope-gradient factor;
C = Cropping-management factor;
P = Erosion-control and support-practice factor.

The rainfall factor (R) summarizes the erosivity of rainfall events in a given location during an average year. The soil-erodibility factor (K) is a characteristic property of a given soil. The product of R and K is the quantity of soil which would be lost in a continously fallow and tilled field that is 72.6 feet long and has a nine percent slope. Slope length is the horizontal distance from the point of origin of overland flow to the point where runoff water enters a defined channel or waterway or sediment deposition beings. Runoff accummulation and thus soil loss per unit of area increases with increased slope length. Increases in the slope of land increase runoff velocity and the ability of runoff to detach and transport soil particles. The slope-gradient factor (S) accounts for the steepness of the slope. The product of the slope-length and slope-gradient factors is defined as the ratio of soil loss per unit of area on a given field to the loss that would occur from a field with a 72.6 foot slope of nine percent.

The product of R, K, L, and S is the estimated average gross soil loss from a continuously fallow field which is tilled. This figure is adjusted downward by the cropping-management factor and the erosion-control and support-practice factor. The erosion-control and support-practice factor (P) is the ratio of soil loss with practices such as contour tillage, contour strip-cropping, or a terrace system to the loss with uphill and downhill culture. The P factor adjusts for supporting actions undertaken to reduce the velocity of runoff. The crop-management factor (C) is the ratio of soil loss in a field cropped and managed in some specified fashion to soil loss in a continuously fallow and tilled field. The C factor adjusts for crops, crop sequences, residue management, tillage practices, and toher cropping and management considerations.

The Effects of Soil Erosion

The loss of soil correspondingly decreases soil depth on eroded areas. Generally the soil removed is the best soil in terms of organic matter and nutrient content. The newly exposed soil is less permeable to water, air, and root growth. The simple loss of depth reduces the root zone for plant growth, decreases the water-holding capacity of the soil, and brings less desirable subsoil layers closer to the surface.

Soil structure is altered in three general ways by erosion (Troeh et al., 50). First, erosion exposes a less friable and less permeable soil or the underlying soil is less granular and porous. Second, raindrops disintegrate aggregates on the surface and a compacted crust is formed. The removal of organic matter by erosion compounds this problem, as organic matter stimulates the formation of desirable aggregate structure. Finally, the rain water carries suspended particles through percolation into the surface pores of the soil. The subsequent reduction in infiltration and permeability increases the runoff of rainfall and decreases the soil's water-holding capacity. Erosion rates increase with the increased rates of runoff.

A substantial amount of nutrients is removed with the soil. Troeh et al. (50) estimated the undiscounted value of nutrients lost in eroded soil at approximately eighteen billion dollars in 1975 prices. While the total amount is not available for plant growth each year, it does represent the loss of a substantial amount of plant nutrients. Rising energy prices may make this loss of nutrients even more costly. Beasley (4) also cites that loss of soil nutrients as a cause of a poorer quality crop lacking in certain nutrients.

The sorting action of water erosion (Troeh et al, 50) tends to remove the finer soil particles, leaving behind coarser material. The gravelly appearance of many eroded areas provides visual testimony to this fact. This sorting action continues to remove finer particles and stones become more prevalent as the covering of topsoil is removed.

Soil erosion from a particular site leads to deposition elsewhere. Commonly assumed sediment delivery ratios of .2 - .4 (Narayanan et al., 34; Sietz et al., 41) imply that over half the soil loss predicted by the USLE is deposited on the land. Productive topsoil may be buried by a poorer soil. Deposition of another soil type could significantly affect the soil texture and structure.

Gully Erosion

Gullies are erosion channels too large to be erased by normal tillage operations (Troeh et al., 50). These are formed fairly rapidly where run-off water concentrates with sufficient flow to cut deeply into the soil (Beasley, 4). Alternate freezing and thawing of exposed steep gully banks, the force of gravity, and seepage tend to cause mass movement of soil from higher to lower levels. Gullies continue to expand until run-off water is diverted and/or sufficient stablizing plant cover is established.

Yield Losses

A major effect of sheet and rill erosion is the loss of productivity. Yields decline as more and more soil is lost. This is evidenced by estimates obtained in the Four Mile Creek Soil Survey (17). Rather than determine the individual impacts on productivity of soil erosion's many effects, the evaluation method discussed in the next chapter assumes measurement of the total effect on yields of all these factors. These factors include the reduced root zone (Neill et al.,36), decreased water-holding capacity, loss of soil nutrients, and poor seed bed (Troeh et al., 50). These factors are attributed to a decreased soil depth, poorer soil structure and texture, and loss of organic matter and nutrients. These yield losses are distributed in the analysis over time corresponding to the cumulative loss of soil. While cropping alone may reduce soil organic matter and damage soil structure, the assumption of constant technologies and maximization of returns over time reduce the importance of this argument in this analysis.

This method incorporates productivity losses from sheet and rill erosion on soil types where erosion occurs. However, there may also be productivity impacts on soil types with little or no erosion where sediment from adjacent slopes is deposited (Beasley, 4). Seeds or young plants may be buried too deeply. This deposition may also increase the water-holding capacity of the area where it occurs. Crops may not be planted, harvested, or grown. This would be an annual cost of soil erosion dependent on the amount of erosion occurring on nearly all soils and the sediment delivery ratio.

Production Costs

Production costs are likely to increase with erosion. Rill erosion leaves channels that must be smoothed, increasing the number of secondary tillage operations or requiring a more erosive primary tillage practice. Proper placement of seeds by a planter may be impossible if the field is too rough. The rills may also cause damage to equipment by their ridged surface. These costs would be linked with annual soil loss. The increased density of the subsoil leads to tillage operations for seedbed preparation or a rotary hoeing early in the growing season.

The increased density of subsoil leads to increased fuel costs and field time as the soil is more resistant to tillage operations (Ayres, 3). This increased resistance results in greater wear on equipment, decreasing its physical life and increasing repair costs. The formation of a surface crust, an effect on soil texture and structure (Troeh et al., 50) may require more tillage operations for seedbed preparation or a rotary hoeing to aid plant emergence. These aspects of soil erosion on production costs can be tied to losses in soil depth.

The loss of nutrients, natural and applied, increases fertilizer costs. Data collected by Borcherding (7) from the study area indicates that fertilizer levels are relatively constant over soils with different degrees of soil depth, even though yields decrease. The economically optimal level of fertilization for a particular soil as recommended by Voss (60) decreases fertilizer levels by the same percentage as the yield decreases. Changes in soil depth, at least in the study area, result in a nonoptimal use of fertilizer.

Sediment deposition can decrease the effective life of soil conservation structures such as terraces and grassed waterways (Beasley, 4). Deposition decreases the effective life of tile outlets and drainageways, requiring additional maintenance. Deposition in fencelines may render the fence ineffective. Road ditches cannot hold as much snow when partially filled with sediment.

Costs of Gully Erosion

Gullies often dissect fields into smaller units as they are too large to cross with tillage equipment. This increases point rows and turning, decreasing yields and increasing production costs on the remaining soil surface (Beasley, 4). Gullies also present a potentially dangerous obstacle to tillage or adjacent cropland.

These costs are minor compared to the immediate and permanent loss of productivity where the gully has formed (Beasley, 4). Gully repair often requires extensive and costly earth-moving operations. Even when stabilized, a certain portion of the productive land base is lost.

Grassed waterways are common in the Four Mile Creek watershed to stabilize or prevent gullies. Much of the impact of gully erosion in a dynamic model has already occurred. By linking a certain percentage of the land base on the watershed with annual erosion, more land becomes available as erosion and the subsequent water runoff are reduced.

Recognition of Onsite Costs

With this extensive list of potential onsite costs of soil erosion, why would one contend that farmers fail to recognize these costs in their use of the soil? Crosson (11) contends that farmers should have the experience, knowledge, and economic incentive to manage the soil wisely. However, the lack of empirical estimation of onsite costs indicates the difficulty in valuing many onsite costs. Another factor is the nonlinear nature of the problem. Many onsite costs occur after substantial soil loss. Soil loss in many areas is just now reaching a level where onsite costs occur.

Farmers often fail to recognize significant erosion losses as evidenced by Nowak and Korsching (38). Soil loss is difficult to measure and substantial losses may not be readily visible. The loss of forty tons of topsoil would decrease soil depth approximately one-quarter of an inch. Sheet erosion is particularly disguised, evidenced only by an occasional depositional delta. Rill erosion disappears following tillage operations. Gully erosion is most obvious to the farmer and generally receives immediate attention.

Some onsite costs occur gradually over time. It may take many years even at high erosion rates to make a substantial impact on yields and production costs. The change is so gradual that it goes undetected. Higher yields and lower costs of the past are forgotten.

The variability of other factors affecting yields and production costs make it difficult to isolate the effects of soil loss. Weather plays a major role in determining costs and yields each year. The USLE itself is based on a ten-year average of rainfall events. This variability makes the identification of trends in yields and costs most difficult to identify.

Erosion is a random event in the production period as well as the long-run. Soil loss occurs only during and briefly after rainfall events. Costs that occur disjointedly from the causal event are difficult to recognize. Attributing these costs to events of a relatively short duration may seem unreasonable.

The distribution of onsite costs over location complicates the identification of erosion's costs. A multitude of soil loss rates can exist in a field, depending on the variety of soils and slopes contained. Substantial productivity losses and cost increases on a small portion of the field have little impact on such measures for the entire unit. Where depostion is a problem, identifying the source of that sediment may be difficult. Identifying the source of erosive water runoff may be difficult as well. The excessive runoff that forms gullies may not be attributed to poor conservation practices on uplying areas.

Just as erosion and its costs may be disassociated, so are the costs and benefits of erosion control. Structures and practices that reduce soil loss serve their purpose mainly during rainfall events and may represent both a nuisance and substantial cost at other times.

Their benefits are long-term, while the costs are immediate. A high discount rate based on borrowed capital reduces the value of this stream of benefits in the future.

The knowledge and experience of a lifetime does not allow the farmer to observe all the costs of erosion. Some of this information is lost with a transfer to new operators. For the tenant, the planning horizon is so short that future costs of soil loss can be ignored. Combined with an absentee landlord lacking the knowledge of the owner/operator, there is little incentive for erosion control by the tenant.

Finally, tradition has an important role in farming practices. New practices incorporating soil conservation may be viewed as more risky than established practices that were successful in the past. The traditional aesthetic values of straight rows, clean rows, and black dirt affect the acceptance of many conservation practices.

Conclusion

A strict empirical valuation of all onsite costs of soil erosion is impossible at the present. More research will establish the relationship between soil loss and its costs. Combining available data and sensitivity analysis of the onsite costs of erosion, one may determine how significant these costs must be to affect the farmer's use of the soil resource.

CHAPTER III. THE PROGRAMMING MODEL

Introduction

A linear programming model of crop production activities in the Four Mile Creek watershed is developed in this chapter. Included in this model are activities that allow for the consideration of onsite costs by soil erosion including productivity losses, increased fuel use and field time, and gully erosion. The first section provides a description of the effects of soil loss on productivity and erosivity followed by a mathematical description of the model. The results generated by the model with different parameters are presented in the following chapter.

Variable factors of agricultural production do not permit an exact representation of the future. Predicting and modelling the effects of soil loss in the present and future is complex enough; forecasting future economic and technological conditions add further complications. Some simplifying assumptions are made to aid in the construction of the model and later analysis. Relative factor and product prices and production technologies, are held constant leaving soil loss as the predominant variable through time. The key elements of the soil resource is the analysis on the depth of soil and, in the case of gully erosion, the stock of land.

Soil Loss Dynamics

Shortle (43) divided soils present in the Four Mile Creek watershed into four management groups, with particular emphasis given to topsoil and subsoil depths and erosivity of the soils. The characteristics of these soil management groups used in the model are obtained as weighted averages of the component soils. This aggregation should correspond with international occurrences comparable treatments are found in a number of watershed studies (Frohberg and Swanson, 18; Narayanan et al., 34; Narayanan and Swanson, 35; Seitz et al., 41; Swanson, 48). Table 3.1 lists the soils in each of the four groups and the total acreage of the groups. Table 3.2 presents the weighted average erosion factors and topsoil depths of the soils in the groups.

The erosion values in Table 3.2 are the product of R, K, S, and L1 or L2 factors of the Universal Soil Loss Equation for unterraced or terraced land, respectively.

While Shortle (43) examined crop production practices in the entire watershed, the Group III management soils are most relevant in the study of onsite costs. There is virtually no erosion hazard or soil loss expected from the Group I soils. The Group II soils are more erosive and have more shallow topsoil than the first group. Yet, Shortle found the onsite costs from soil loss were expected to be negligible. Based on USDA (53) estimating procedures, a loss of 4.61 inches of topsoil would be required before any losses

Table 3.1 Four Mile Creek soil management groups (Shortle, 43)

Management group	Acreage	Soils		
I	2545	118	119	122
		133	430	933
		428B	933B	
II	4385	008B	011B	119B
		120B	162B	377B
III	4822	120C2	162C2	179C2
		377C2	120D2	162D2
		179D2	377D2	683D2
		763D2	120D3	162D3
		179D3	192D3	377D3
		683D2	763D3	
IV	601	162E2	162E3	162F2
		162F3	179E2	179E3
		192E3	763E2	763E3
		763F3		

Table 3.2. Group soil depths and erosivity (Shortle, 43)

Management Soil group	RKSL1[a] (tons/acre yr.)	RKSL2[b] (tons/acre yr.)	Average topsoil depth[c] (inches)
I	6.46	6.28	more than 20
II	22.25	19.06	16.39
III	114.39	70.62	6.34
IV	357.65	215.97	less than 3

[a]RKSL1 is the weighted average of the products of the R, K, S, and L factors of the USLE of the soils in the group for unterraced land.

[b]RKSL2 is the weighted average of the products of the R, K, S, and L factors of the USLE of the soils in the group for terraced land.

[c]Topsoil depths are determined for individual soils by assuming that soils in erosion phases zero and one have the maximum topsoil depth indicated in the Four Mile Creek Soil Survey (17). Soils in erosion phase two are assumed to have seven inches which is the typical maximum for a soil to be in erosion phase two. Soils in erosion phase three are assumed to have depths of three inches which is the typical maximum depth for a soil in phase three.

in yield occur.[1] Under conventional cropping practices used in the watershed, it would take nearly one hundred years before losses of productive capacity of any magnitude would begin. Finally, the Group IV soils are steep, shallow, highly erosive, and unproductive. Presently, these soils are used primarily for permanent pasture. This makes these soils irrelevant for the consideration of onsite costs with different crop management strategies.

The Group III model

The soils in the third management group are in erosion phases two and three and consequently some productivity losses have already occurred. This is supported in a recent soil survey of the watershed (Four Mile Creek Soil Survey, 17). Comparison of crop yield estimates in the survey for soils which differ only in erosion phase show the higher phase soils to have consistently lower crop yields. Based on the data in the soil survey, and the USDA procedures cited earlier, estimates of yield losses of 0.44 bushels of corn, 0.14 bushels of soybeans, 0.38 bushels of oats, and 0.01 tons of hay will

---

[1]The soils in Group II are indicated by Table 3.2 to have an average soil depth of 16 inches. Based on the procedures used by Shortle (43), mixing of topsoil with subsoil would not be expected with tillage until the soil depth has been decreased to twelve inches.

occur with each inch of soil loss[1]. The quality of subsoils helps keep these losses relatively small.

In addition to decreasing yield potentials, the reduction of soil depth increases the erosivity of the soils. The gross soil loss estimates utilized in this study are obtained by application of the USLE. The crop practice and management factors of the soil loss model for the Group III soils are reported by the USDA (55). Proceeding in the same manner outlined before for yield losses with loss of soil (see footnote 1, page 26), Shortle (43) determined that each inch of soil loss in Group III will bring about an increase in the value of RKSL1 by 2.99 tons per acre per year and an increase in the value of RKSL2 by 1.66 tons per acre per year. The initial values of RKSL1 and RKSL2 are given in Table 3.2.

While the productivity losses and effects of increasing erosivity are not of substantial magnitude, any arguments to the effect that current decisions on future production possibilities will not be

---

[1]The soil survey provides crop yields under high management conditions for various soils in the erosion phases that occur in the area. The USDA procedures indicate that approximately six inches of soil loss are required to move from erosion phase one to erosion phase two and that approximately twelve inches of soil loss are required to move from erosion phase two to erosion phase three. The soils in Group III are erosion phase two or erosion phase three. The yield loss from soil phase two to soil phase three is assumed to continue as the soils move from erosion phase three to subsoil. The Group III losses that occur are weighted averages of those occurring on the individual soils (Shortle, 43).

significantly influenced by these impacts cannot without analysis be made as the losses may occur so near in the future. Furthermore, the inclusion of some cost estimate for the other onsite effects discussed in Chapter II increase the significance of soil loss on future returns. It is for this reason that a multi-period model of crop production is needed for the analysis of this group of soils.

Crop Practices

The five crops compromising the rotations in the model are corn, soybeans, oats, hay and permanent pasture. There are three alternative crop mixes or rotations for the Group III soils. The first, represented as C-B-C-B-C, is corn followed by soybeans followed by corn followed by soybeans followed by corn. The first corn crop is assumed to follow corn. The second, C-C-O-M-M, is corn followed by corn followed by oats followed by two years of meadow. The first corn crop is assumed to follow two years of meadow. Finally, a permanent pasture option, P-P, was available.

This selection of rotations allows for solutions fairly representative of current production and responses to productivity losses and erosion control needs. The C-B-C-B-C rotation is the most profitable and erosive, while permanent pasture is least profitable and assumed to have no erosion. Output prices are listed in Table 3.3 and are considered representative of expected relative prices.

Table 3.3. Crop price assumptions

Crop	Price
Corn	$3.50 per bushel
Soybeans	$7.50 per bushel
Oats	$1.50 per bushel
Straw	$37.50 per ton
Hay	$15.00 per ton of forage yield

The limitation of only two available crop rotations is eased by the interpretation of activity levels in the linear programming model results. If the C-B-C-B-C and C-C-O-M-M rotations enter in the solution in the same time period, the rotation used in that period may be viewed as a linear combination of the two rotations over all acres rather than separate rotations on different acres. The actual rotation would be a weighted average of the two available. The opportunity is available through this process to trade highly erosive and more profitable crop practices for less erosive and less profitable ones on a contინous basis.

Livestock activities in the model would have little impact on the results. There is sufficient permanent pasture provided by the Group IV soil to meet the grazing needs of current livestock levels in the area (Miranowski et al., 33). While livestock activities in a static model may provide a relatively higher value to feed grain production, in a long run dynamic model an equilibrium would be achieved between market prices and the feed value of grains.

Crop Yield Data

The Four Mile Creek Soil Survey (17) provided basic yield estimates for existing soil depths. These estimates were adjusted for tillage practices and rotations based on data in Miranowski et al. (33). Yield penalties of two percent for fall chisel, four percent for spring disk, five percent for spring chisel, and ten percent for no-till relative to the fall moldboard tillage practice are applied. The study by Miranowski et al. (33) showed that a five percent yield increase for corn following soybeans and a ten percent yield increase for corn following second-year meadow due primarily to nitrogen carryover is obtained relative to a continuous corn rotation. The study showed no yield losses were associated to contouring, but that a five percent yield loss occurred on the average with a change to farming terraced acres relative to straight row cultivation.

Tillage Practices and Costs

There are five different tillage practices in the model for production of the C-B-C-B-C rotation. These include a fall moldboard plow, fall chisel plow, spring chisel plow, spring disk, and no-till option. The no-till option was eliminated for the C-C-O-M-M rotation due to problems of no-till planting corn after meadow. This selection of tillage practices is based on current practices in the area to privide a fairly wide range of income and erosion alternatives. Table 3.4 presents a summary of current tillage practices in the area for the crops included in the rotation.

The spring moldboard plow tillage practices was eliminated as the practice was less-profitable and more erosive than the spring chisel plow option. This practice would never enter the solution, whether the incentive was for higher income or less erosion. While the no-till option is not currently used in the area, it is included to provide a C-B-C-B-C tillage practice with a relatively low erosion level.

The secondary tillage practices that follow each of the primary tillage options are based upon actual practices in the area as well. Farmers may respond to a reduction in the intensity of primary tillage by increasing the intensity of secondary tillage (Schaller and Ameyiya, 40). This model avoids the common assumption that secondary tillage activities are conducted at a minimum frequency.

Table 3.5 indicates the secondary tillage practices used in the area with each primary tillage practice for each crop in the entire watershed, with no distinction made for particular soil types. The farmer may use a secondary tillage practice only once during a particular year but twice the next year with the same primary tillage practice due to variable environmental conditions. Fractional values represent average values over time. With the exception of fall chisel plowing it can be seen that secondary tillage operations increase as primary tillage intensity decreases. The secondary tillage operations

Table 3.4. Tillage practices in Four Mile Creek (Miranowski et al., 71)

Rotation	Number of farmers using practice					
	Moldboard		Chisel		Disk only	
	Fall	Spring	Fall	Spring	Fall	Spring
Continuous corn	5	4	11	2	2	4
Corn after beans	0	0	2	0	6	28
Beans after corn	3	11	11	2	1	7
Corn after meadow	4	17	3	0	2	0

Table 3.5.
Frequency of secondary tillage practices in Four Mile Creek (Miranowski et al., 71)

Crop	Primary tillage	Fall disk	Spring disk	Field cond.	Harrow	Rotary hoe	Cultivate	Planting date (May 1=120)
Continuous corn	Fall plow	1	1	1		1	1.66	122
	Spring plow	0	2	1	1	1	1.75	125
	Fall chisel	.5	1	1		.5	1.5	124
	Spring chisel		2	1		1	1.5	126
	Disk only		3	1.5		.5	1.3	129
Corn after beans	Fall chisel		1	1		1	1	128
	Spring disk		2	1		1	1.5	124
Corn after meadow	Fall plow		1.5	1	.5	.5	1.5	126
	Spring plow		2	1	.5	.5	1.66	127
	Fall chisel		1.5	.5		0	1.5	122
	Disk only		2	2		0	1	125
Beans after corn	Fall plow	.5	1.5	.5	.5	0	1.5	119
	Spring plow		2	.75	.5	0	1.5	138
	Fall chisel	.5	1.5	1		1	1	130
	Spring disk	.5	2	1	.25	0	2	135

associated with fall chisel plowing are almost identical to those with fall moldboard plowing. Since the chisel plow requires less time and fuel per acre, the cost-savings of fall chisel tillage would make it more profitable than fall moldboard tillage, except for a later planting date that could decrease expected yields. The per acre costs of each tillage practice for each rotation were obtained by use of the Oklahoma State Budget Generator (Kletke, 25) with adjustments made for the additional costs of field operations conducted on contoured and terraced acres. Representative machinery complements for crop production in the area were developed from a survey of machinery inventories in the area by Miranowski et al. (33). Fertilizer application rates are based upon recommendations for soils in the area developed by Voss (60). Herbicide and insecticide application rates are based upon use data developed for Iowa regions by Jennings and Stockdale (24) and recommendation contained in a Felco Land O'Lakes (15) guideline. The costs of application methods are based upon actual practices as determined by Miranowski et al. (33).

The per acre cost of tillage practices is inflated on contoured and terraced acres. Contouring increases field time and fuel usage as a result of additional time required to perform field operations relative to straight-row culture. Based upon the survey by Miranowski et al. (33) and data developed by Walker (62) the labor costs obtained from the budget generator and fuel costs were inflated by five percent on B slopes, seven percent on C slopes, and nine percent on D slopes.

Costs were increased by another two percent on terraced acres corresponding to farmer information (Miranowski et al., 33).

The Structure of the Model

The objective function

The objective function of the model is to maximize the present value of the cash flow from production activities for a period of fifty years less the present value of productivity losses, that with present knowledge and technology, continue into perpetuity. The penalty function is constructed to reflect the opportunity cost imposed in future years by the soil losses resulting from production during the period under consideration. This allows the investigation of crop production patterns and technology of a farmer trying to maximize the net present value of production for a fifty year planning period, with some concern for future productivity as well.

By approximating the effects of soil loss as linear over time, the stock effects problem may be treated as a problem in the use of layers of the soil resource. The current soil depth is divided into two-inch soil layers where crop production activity yields and erosion coefficients are associated with particular soil layers. These layers are depleted by erosion over time. The restrictions on the model provide a logical order in the use of these layers.

Let A_{jt} be a m x 1 vector of acres in available crop production activities in period t if D(j-1) inches of soil have been lost to erosion but $D(j)$ inches have not ($j = 1, 2, \ldots$). If no soil has been lost to erosion, then A_{1t} is a vector of acres in activities available in period t and A_{jt} is the vector of acres in available crop production activities if only the first D inches have been lost. The number of these vectors needed in the model can be reduced by calculating the maximum amount of soil loss that can occur in any period t. The number of vectors of available crop production activities at various soil loss levels in each period was limited by the fact that even the most erosive crop practice could not deplete an entire layer in one period. For the period t = a, the only vector needed $\overset{S}{\text{in}}$ vector A_{11}. Depending on the level of erosion in period t, the vector to be used in the period t = 2 are A_{12} and A_{22}.

The implication is that while vector A_{jt} may be permissible in period t, another vector $A_{(j+\lambda)t}$ may not where λ is a positive integer. However, since erosion may be much less than the maximum using restrictive practices it must be true that if A_{jt} is permissible then $A_{j(t+\lambda)}$ must also be permissible. The maximum value of j which can be reached at the end of period t will be denoted by m_t'.

Let B_{jt} be an n x m matrix of output coefficients applicable under high management conditions and S_{jt} be a 1 x m vector of soil loss coefficients used in the model when $D(j-1)$ inches of the initial soil depth have been lost. The reduction in productivity from soil loss is shown where $B_{jt} > B_{kt}$ if $k > j$. Similarly, the increase in soil erosivity from soil loss is shown where $S_{jt} < S_{kt}$ if $k > j$.

Let C_{jt} be a 1 x m vector of discounted activity cost coefficients associated with vector A_{jt}. The increased use of fuel and higher labor coefficients due to soil loss leads to the case where $C_{jt} < C_{kt}$ if $k > j$. Fuel use and field time increase as soil depth diminishes due to the greater bulk density of the subsurface. These costs were adjusted .25% per inch based on the percentage change in soil density. The S_{jt} vector of soil loss coefficients may be multiplied by $k <_t$ where K represents a 1 x 1 vector of the discounted value of the cost of each ton of soil loss in period t. When K is set equal to zero, it implies that there are no additional onsite costs of soil loss that need to be included in the model. However, increasing the value of K to various levels can be used to determine the sensitivity of the model to onsite costs of soil loss not considered or measured in the model. These costs include potential depositional damage, additional machinery costs and repairs, and any other possible impacts of soil loss. Because these costs have not been empirically estimated, relatively conservative levels are employed in the analysis.

The objective function for the Group III soils can be written as

$$\sum_{t=1}^{T} \sum_{j=1}^{m_t'} (P_t B_{jt} - C_{jt} - K_t \cdot S_{jt}) A_{jt} - \hat{V}_T CE_T \qquad (1)$$

Where P_t is the discounted price of outputs in period t, $A_{jt} \geq 0$ for all $j = 1, 2, \ldots, m_t'$ and $t = 1, 2, \ldots, T$, and $\hat{V}_T$ is the present value of the penalty function coefficient and CE_T is cumulative erosion through time T or

$$CE_T = \sum_{t=1}^{T} \sum_{j=1}^{m_t'} S_{jt} A_{jt} \tag{2}$$

where W is the volume of D - L acre inches of soil, the maximization of the objective function has m_t' constraints of the form

$$\sum_{t=1}^{T} S_{jt} A_{jt} \leq W \tag{3}$$

where L is the land area of the Group III soils, there are T constraints on the objective function written as

$$\sum_{j=1}^{m_t'} A_{jt} \leq L - G \cdot \sum_{t=1}^{T} \sum_{j=1}^{m_t'} S_{jt} A_{jt} \tag{4}$$

Where G is a constant representing the reduction in the land base due to gully erosion from each ton of soil over time. Examination of aerial photographs (Borcherding, 7) indicates substantial acreage is in grassed waterways, primarily as a means of gully erosion control.

It is assumed that once an acre is cultivated on the contour, it is contoured through the rest of the time periods in the model. This is also true for acres that are terraced. The contour layout is assumed not to depreciate, while terraces are to be replaced every twenty-five years. The costs of contouring and terracing are charged in full in the time period in which the contour or terrace is first employed. The cost is reduced in later time periods to eliminate the biases that would arise if the full costs were charged without accounting for the stream of benefits from either practice that would occur beyond the fiftieth year.

CHAPTER IV. RESULTS

Introduction

The purpose of this paper is to analyze the importance of onsite costs to the profit maximizing producer in his use of the soil resource over time, and how the consideration of different levels of previously unrecognized onsite costs would affect this use. One may look at tillage practices, crop rotations, and conservation practices, and most importantly, the levels of income and soil loss associated with these onsite costs. The use of different discount rates is important to reflect the difference in public and private interest in conserving the soil resource and their planning horizons, as well as the costs of capital. Finally, valuation of all onsite costs by the producer may reduce soil loss and the resulting levels of pollution to more tolerable levels, lessening the need for regulation or the cost through subsidization for soil erosion control by the public sector.

The Group III soils are where most of the dynamics of soil loss become evident. Soil loss levels are significant with most crop practices, indicating substantial losses in soil depth over the time period of the model.

Baselines

The baseline solution included only productivity losses and increased fuel and field time as onsite costs of soil erosion. The solutions were identical at both the five and ten percent rates of discount. These results are presented for the ten percent rate in Table 4.1. Application of a five percent discount rate increased the present value of this pattern of soil use to $12338225, an increase of one hundred eighty percent.

A C-B-C-B-C crop rotation using a fall chisel tillage practice with no contouring was used during all fifty years of the solution. Corn production fell eleven percent and bean production dropped four percent from productivity losses as soil depth decreased. Average annual net income declined ten percent from these lower yields and increasing costs. While the crop management factor was constant throughout, annual soil loss increased thirty percent caused by changes in the USLE for Group III soils as topsoil depth diminished.

Nearly thirteen inches of topsoil was lost during the fifty year time period. While the penalty cost function places a higher value on this loss of soil at the five percent rate of discount, as well as productivity in the latter periods of the solution, the magnitude of this value is fairly small. The loss of an inch of topsoil per acre presents an opportunity cost of $24.60 at the end of fifty years, assuming the most profitable rotation of C-B-C-B-C. Discounted to the present, this value is $2.41. The present value of soil loss per ton is less than two cents. The ten percent discount rate places an even lower present value on soil loss at the terminal period.

Table 4.1. Baseline solution at a ten percent discount rate

Net Present Value of Program	$6762301.
Loss of Depth on Group III Soils	12.99 inches

Time Period:	Crop Rotation	Tillage Practice
Years 1-5	C-B-C-B-C	Fall chisel
6-10	C-B-C-B-C	Fall chisel
11-15	C-B-C-B-C	Fall chisel
16-20	C-B-C-B-C	Fall chisel
21-25	C-B-C-B-C	Fall chisel
26-30	C-B-C-B-C	Fall chisel
31-35	C-B-C-B-C	Fall chisel
36-40	C-B-C-B-C	Fall chisel
41-45	C-B-C-B-C	Fall chisel
46-50	C-B-C-B-C	Fall chisel

Time Period:	Average Annual Gross Soil Loss (1000 tons)
Years 1-5	144
6-10	145
11-15	151
16-20	155
21-25	158
26-30	166
31-35	170
36-40	174
41-45	181
46-50	186

Management Practice	Annual Corn Production (1000 bushels)	Annual Soybean Production (1000 bushels)
Straight row	300	71
Straight row	299	71
Straight row	297	71
Straight row	296	70
Straight row	295	70
Straight row	292	70
Straight row	291	69
Straight row	290	69
Straight row	287	69
Straight row	286	68

Average Annual Net Income (1000 dollars undiscounted)
693
690
682
675
670
659
653
646
636
628

Onsite Costs of Soil Loss

A charge of $.05 per ton of soil loss was imposed on the model to represent unrecognized costs of soil erosion as noted in the previous chapter. This charge did not change the results of the model from the baseline at either level of the discount rate, except for a small decrease in annual income and net present value.

Increasing this charge to $.10 per ton introduced contouring at year twenty-one into the solutions at both discount rates. Again, the five percent discount rate produced a solution identical to the ten percent rate (Table 4.2) excepting the higher net present value of $12200614 compared to $6615888 at a ten percent rate.

Annual corn production declined only four percent and soybean production fell three percent over the fifty years. Average annual net income declined ten percent. While yields were higher than the baseline, income was reduced due to the increased costs of contour farming and the additional onsite costs.

Most significantly, soil depth decreased by only twelve inches, a savings of nearly one inch from the baseline. The increase in soil erosivity was not as great as average annual gross soil loss rose only fifteen percent. Annual erosion, while identical to the baseline solution in the early years, dropped to ninety percent of baseline levels in the later period.

At a level of $.25 per ton charged for onsite costs all crops were farmed on the contour. The five and ten percent discount rates produced

Table 4.2. $.10 per ton additional charge to onsite costs at a ten percent discount rate

Net Present Value of Program	$6615888.
Loss of Depth on Group III Soils	12.00 inches

Time Period:	Crop Rotation	Tillage Practice
Years 1-5	C-B-C-B-C	Fall chisel
6-10	C-B-C-B-C	Fall chisel
11-15	C-B-C-B-C	Fall chisel
16-20	C-B-C-B-C	Fall chisel
21-25	C-B-C-B-C	Fall chisel
26-30	C-B-C-B-C	Fall chisel
31-35	C-B-C-B-C	Fall chisel
36-40	C-B-C-B-C	Fall chisel
41-45	C-B-C-B-C	Fall chisel
46-50	C-B-C-B-C	Fall chisel

Time Period:	Average Annual Gross Soil Loss (1000 tons)
Years 1-5	144
6-10	145
11-15	151
16-20	152
21-25	154
26-30	160
31-35	163
36-40	168
41-45	169
46-50	169

Management Practice	Annual Corn Production (1000 bushels)	Annual Soybean Production (1000 bushels)	Average Annual Net Income (1000 dollars undiscounted)
Straight row	300	71	679
Straight row	299	71	676
Straight row	297	71	666
Straight row	296	70	659
Straight row/contour	295	70	654
Straight row/contour	292	70	642
Straight row/contour	291	69	637
Straight row/contour	290	69	629
Straight row/contour	288	69	618
Straight row/contour	287	69	608

identical solutions (Table 4.3). The net present values were $11847469 and $6459261, respectively. This is nearly ninety-six percent of the baseline values.

Corn production fell only three percent and soybean production fell only one percent during the fifty years, and annual production was three percent greater than the baseline during the last fifteen years. Annual net income fell only five percent through the fifty years, and was ninety-nine percent of the baseline annual net income in the last five years.

Gully Erosion

The most unique aspect of the analysis is the consideration of gully erosion in the model. If one assumes that five percent of the land base is lost to gullies or in a gully erosion control practice throughout the fifty years then production from two hundred twenty-four acres of the Group III soils is lost. This amounts to a decrease in the average annual net income of approximately $28000 in the baseline solution. The net present value of the program would be reduced by $277600 at the ten percent discount rate and $511800 at the five percent rate. There would also be corresponding reductions in crop production and annual gross soil loss values. The remaining acres would still lose thirteen inches of topsoil, however.

If farmers can reduce the land lost to gullies by reducing erosion, the costs of erosion control may be partially offset by increasing the productive land base. The analysis assumed that current erosion

Table 4.3. $.25 per ton additional charge to onsite costs at a ten percent discount rate

Net Present Value of Program	$6459261.
Loss of Depth on Group III Soils	6.98 inches

Time Period:	Crop Rotation	Tillage Practice
Years 1-5	C-B-C-B-C	Fall chisel
6-10	C-B-C-B-C	Fall chisel
11-15	C-B-C-B-C	Fall chisel
16-20	C-B-C-B-C	Fall chisel
21-25	C-B-C-B-C	Fall chisel
26-30	C-B-C-B-C	Fall chisel
31-35	C-B-C-B-C	Fall chisel
36-40	C-B-C-B-C	Fall chisel
41-45	C-B-C-B-C	Fall chisel
46-50	C-B-C-B-C	Fall chisel

Time Period	Average Annual Gross Soil Loss (1000 tons)
Years 1-5	82
6-10	82
11-15	82
16-20	86
21-25	86
26-30	86
31-35	92
36-40	92
41-45	93
46-50	96

Management Practice	Annual Corn Production (1000 bushels)	Annual Soybean Production (1000 bushels)	Average Annual Net Income (1000 dollars undiscounted)
Contour	300	71	657
Contour	300	71	657
Contour	300	71	657
Contour	297	71	657
Contour	297	71	644
Contour	297	71	644
Contour	295	70	631
Contour	295	70	631
Contour	294	70	628
Contour	292	70	619

levels as determined by the baseline were directly proportional to the acres lost to gullies. Thus any reduction in erosion would increase the acres available for crop production.

Using a ten percent discount rate, this linkage reduced depth loss to 11.72 inches (Table 4.4). Acres lost to gullies were cut in half. Adjusting the baseline figures according to the reduction in the land base of two hundred twenty-four acres as discussed earlier, income and crop production levels were nearly identical. However, average annual gross soil loss was reduced fifteen percent by the last period. Contouring was introduced in the sixteenth year.

At a discount rate of five percent, the land lost to gullies was more highly valued and there was a greater incentive to reduce soil loss (Table 4.5). Again, adjusting the baseline according to the loss of two hundred twenty-four acres would produce nearly identical levels of crop production, income, and net present value. However, the acres lost to gullies was only about thirty-five percent of that in the baseline. Average annual gross soil loss was sixty percent of baseline levels, and only 8.00 inches of soil depth were lost.

A "Monson" Solution

A review of the second chapter indicates that productivity losses and increased fuel use and field time are not the only onsite costs of soil erosion, but an empirical estimation of other random onsite

Table 4.4. Soil base of five percent linked with gully erosion at a ten percent discount rate

Net Present Value of Program	$6591192.
Loss of Depth on Group III Soils	11.72 inches

Time Period:	Crop Rotation	Tillage Practice
Years 1-5	C-B-C-B-C	Fall chisel
6-10	C-B-C-B-C	Fall chisel
11-15	C-B-C-B-C	Fall chisel
16-20	C-B-C-B-C	Fall chisel
21-25	C-B-C-B-C	Fall chisel
26-30	C-B-C-B-C	Fall chisel
31-35	C-B-C-B-C	Fall chisel
36-40	C-B-C-B-C	Fall chisel
41-45	C-B-C-B-C	Fall chisel
46-50	C-B-C-B-C	Fall chisel

Time Period:	Acres Lost to Gullies (Erosion/Control)
Years 1-5	113
6-10	113
11-15	114
16-20	116
21-25	117
26-30	117
31-35	117
36-40	123
41-45	126
46-50	127

Management Practice	Annual Corn Production (1000 bushels)	Annual Soybean Production (1000 bushels)	Average Annual Gross Soil Loss (1000 tons)	Average Annual Net Income (1000 dollars undiscounted)
Straight row	292	69	140	676
Straight row	292	69	141	673
Straight row	289	69	147	664
Straight row/contour	288	69	141	656
Straight row/contour	287	68	143	652
Straight row/contour	285	68	145	640
Straight row/contour	285	68	145	640
Straight row/contour	282	67	153	626
Straight row/contour	281	67	156	621
Straight row/contour	280	67	158	617

Table 4.5. Soil base of five percent linked with gully erosion at a five percent discount rate

Net Present Value of Program	$12057797.
Loss of Depth on Group III Soils	8.00 inches

Time Period:	Crop Rotation	Tillage Practice
Years 1-5	C-B-C-B-C	Fall chisel
6-10	C-B-C-B-C	Fall chisel
11-15	C-B-C-B-C	Fall chisel
16-20	C-B-C-B-C	Fall chisel
21-25	C-B-C-B-C	Fall chisel
26-30	C-B-C-B-C	Fall chisel
31-35	C-B-C-B-C	Fall chisel
36-40	C-B-C-B-C	Fall chisel
41-45	C-B-C-B-C	Fall chisel
46-50	C-B-C-B-C	Fall chisel

Time Period:	Acres Lost to Gullies (Erosion/Control)
Years 1-5	75
6-10	76
11-15	76
16-20	80
21-25	80
26-30	80
31-35	85
36-40	85
41-45	86
46-50	87

Management Practice	Annual Corn Production (1000 bushels)	Annual Soybean Production (1000 bushels)
Contour/straight row	295	70
Contour/straight row	294	70
Contour/straight row	294	70
Contour/straight row	293	70
Contour/straight row	291	69
Contour/straight row	291	69
Contour/straight row	289	69
Contour/straight row	289	69
Contour/straight row	287	69
Contour/straight row	286	68

Average Annual Gross Soil Loss (1000 tons)	Average Annual Net Income (1000 dollars undiscounted)
93	669
95	667
95	667
97	661
99	655
99	655
105	643
105	643
107	638
108	634

costs would be very difficult. Even if a value could be estimated, at best it would represent some average of actual costs, as the cost would vary with the practices of each individual producer and variable environmental conditions. A level of ten cents was used to estimate an average of these onsite costs.

While there is no empirical data linking soil loss and decreases in the land base from gully erosion, the hypothetical model discussed above is included. The reduction in runoff necessary to decrease soil loss should have some effect on gully formation.

The final problem pertaining to this model is the selection of an appropriate real discount rate. The discount rate should be one that is relevant to the producer. The analysis assumed this real rate of discount to be ten percent.

The model solution with these parameters is presented in Table 4.6. The loss in soil depth was reduced to 6.88 inches and the acres lost to gullies were seventy-five percent of the acres lost under the gully erosion solution alone (Table 4.4). If one considers the adjustments made to the baseline described in the previous section, the production practices used in this solution may represent a better alternative than those of the baseline or gully erosion solution, as crop production was higher in all years and annual net income was higher than the gully erosion solution after the twenty-sixth year.

Producers rely more heavily on contour farming to conserve soil than in the other solutions. Although the crop rotations and tillage

Table 4.6. $.10 per ton additional charge to onstie costs and gully erosion linkage at a ten percent discount rate

Net Present Value of Program	$6484445.
Loss of Depth on Group III Soils	6.88 inches

Time Period:	Crop Rotation	Tillage Practice
Years 1-5	C-B-C-B-C	Fall chisel
6-10	C-B-C-B-C	Fall chisel
11-15	C-B-C-B-C	Fall chisel
16-20	C-B-C-B-C	Fall chisel
21-25	C-B-C-B-C	Fall chisel
26-30	C-B-C-B-C	Fall chisel
31-35	C-B-C-B-C	Fall chisel
36-40	C-B-C-B-C	Fall chisel
41-45	C-B-C-B-C	Fall chisel
46-50	C-B-C-B-C	Fall chisel

Time Period:	Acres Lost to Gullies (Erosion/Control)
Years 1-5	65
6-10	65
11-15	65
16-20	67
21-25	68
26-30	68
31-35	72
36-40	73
41-45	73
46-50	75

Management Practice	Annual Corn Production (1000 bushels)	Annual Soybean Production (1000 bushels)	Average Annual Gross Soil Loss (1000 tons)	Average Annual Net Income (1000 dollars undiscounted)
Contour/straight row	295	70	81	659
Contour/straight row	295	70	81	660
Contour/straight row	295	70	81	660
Contour/straight row	293	70	84	649
Contour/straight row	293	70	85	647
Contour/straight row	293	70	85	647
Contour/straight row	290	69	90	636
Contour/straight row	290	69	90	635
Contour/straight row	289	69	91	633
Contour/straight row	287	69	94	622

practices were identical average annual gross soil loss was fifty percent of the baseline level and seventy-five percent of the gully erosion solution.

Summary

The different solutions indicate that neither the level of onsite costs nor the discount rate affect the crop rotation or tillage practice selection. The income penalty associated with a less-erosive rotation outweighs the accompanying reduction in onsite costs. The same must be true of the tillage practice alternatives. The yield penalties of these tillage practices also have a higher value than the soil that would be saved. The cost of contouring, including fuel use, labor, and installation must be less than the value of the soil conserved.

The value placed on onsite costs had a significant impact on the optimal rate of erosion. A ten cent charge per ton reduced erosion over the fifty years by eight percent from the baseline. Raising the level to twenty-five cents per ton reduced this loss of soil by forty-six percent. Productivity declines were also reduced. At the twenty-five cent level of onsite costs the present value of the solution was reduced four percent.

The solutions with a gully erosion linkage at a ten percent discount rate are shown in the summary table (Table 4.7). Adjusting the baseline solution for two hundred twenty-four acres in gullies or grassed waterways would lower its present value to a level where acres lost to gullies is reduced. If the relationship between gullies and soil loss used in the model was applied, a ten percent reduction in soil depth loss could be achieved with positive income benefits. A forty-seven percent reduction in soil depth loss could be achieved with the last solution at a very small decrease in net present value.

Table 4.7. Summary of results at a ten percent discount rate

Solutions	Reduction of Soil Depth Loss	(%)	Reduction of Net Present Value	(%)
Baseline	----	---	-------	---
$.10 per ton additional charge to onsite costs	.99	8%	$146413.	2%
$.25 per ton additional charge to onsite costs	6.01	46%	$303040.	4%
Gully erosion linkage	1.27	10%	--------	---
$.10 per ton additional charge to onsite costs and gully erosion linkage	6.11	47%	--------	---

CHAPTER V. CONCLUSIONS

Research Needs

The dynamic nature of the problems and costs of soil loss makes it difficult to value the results of the model. The similarity of practices used in the initial period does not indicate the degree of the farmer's awareness of onsite costs. The farmer may be on any of the management paths determined by the model. If farmer awareness of onsite costs is high, empirical determination of onsite costs is useful as a tool to understand his management practice selection. If awareness is low, the importance of determining and relaying these onsite costs to the farmer allows him to better select these practices.

The results show that relatively small onsite costs of soil loss can significantly affect the farmer's use of soil over time. Productivity losses and increased fuel use and field time have little effect on soil erosion at the discount rates used in the model. Combining these costs with some charge per ton of soil loss and linking this soil loss with gully erosion causes a major reduction in soil loss even at a high discount rate. The results indicate that an empirical valuation of onsite costs is needed and that this information transmitted to the farmer would increase his incentive for soil conservation.

The cost of soil loss to the farmer at the termination of his use of the soil is difficult to estimate. The loss in productivity on a farm is a poor estimate of this cost, as so many factors determine the valuation of land. The value placed on the soil's productivity may be subjectively determined by the farmer, placing a high value on the transfer of a productive farming unit to future generations. Market forces may not reflect productivity differences in soils.

The loss of land to gully erosion or its control is an important factor in the optimal rate of soil use. This loss of productive acres represents a sizeable onsite cost that may be quite important in terms of profitable rates of erosion. Again, an empirical data base is needed to better incorporate this aspect of soil loss in the farmer's decision-making process.

The use of soil conserving practices and structures may be changed significantly if linked more directly to onsite costs than through gross soil loss. Certain structures such as terraces may more effectively control gullies than would be indicated by the reduction in soil loss they provide. While economic incentives and stewardship influence the adoption of terraces in the watershed, there may be particularly high onsite costs of soil loss that motivate their construction.

Significance

The consideration of onsite costs in the farmer's decision process may have an effect on the offsite costs of soil loss. Onsite costs of a relatively small value can produce significantly lower levels of gross soil loss. These lower levels should produce lower levels of offsite damage, as sediment and associated pollutants reaching streams would drop. Onsite costs may be so high to the producer that he could reduce soil loss in his own interest to tolerable levels for the public in terms of pollution and future productivity needs.

Such a substantial voluntary reduction in gross soil loss is too much to hope for. Onsite costs may motivate farmers to reduce soil loss levels somewhat, but not to the extent that offsite damage is eliminated. However, the cost that society must bear to reduce soil loss to an acceptable level would be diminished. The need for regulation and subsidization to control offsite damages of soil loss may not be as important as an emphasis in determining onsite costs and relaying this information to the farmer may be a more effective way to reduce the soil loss damages imposed on society.

REFERENCES

1. Alt, Klaus Friedrich. An Economic Analysis of Field Crop Production, Insecticide Use and Soil Erosion in a Subbasin of the Iowa River. Ph.D. dissertation, Library, Iowa State University, Ames, Iowa, 1976.

2. Alt, Klaus Friedrich and Heady, Earl O. Economics and the Environment: Impacts of Erosion Restraint on Crop Production in the Iowa River Basin. Iowa State University Center for Agriculture and Rural Development, CARD Report 75, December 1977.

3. Ayres, George E. Fuel Required for Field Operations, Cooperative Extension Service, Iowa State University, Ames, Iowa, PM-709, November 1976.

4. Beasley R. P. Erosion and Sediment Pollution Control. Ames: The Iowa State University Press, 1972.

5. Boggess, W., McGrann, James, Heady, Earl O., and Boehlje, M. A Farm Level Financial Analysis of Alternative Soil Loss Control Policies. A paper for the American Agriculture Economics Association Meetings. Department of Economics, Iowa State University, Ames, Iowa, 1978.

6. Boggess, W., Miranowski, J., Alt, Klaus, and Heady, Earl O. Sediment Damage and Farm Production Costs - A Multiple Objective analysis. North Central Journal of Agricultural Economics 2, No. 2 (July 1980):107-112.

7. Borcherding, Marvin A. Four-Mile Creek Data, 1976-1979 unpublished, Agricultural Engineering, Iowa State University, Ames, Iowa.

8. Bunce, Arthur F. The Economics of Soil Conservation. Ames: Iowa State University Press, 1945.

9. Burt, Oscar R. Farm Level Impacts of Soil Conservation in the Palouse Area of the Northwest. American Journal of Agricultural Economics, 63, No. 1 (February 1981):83-92.

10. Burt, Oscar R. and Cummings, Ronald G. Production and Investment in Natural Resource Industries. American Economic Review 60, No. 4 (1970):576-590.

11. Crosson Pierre. Diverging Interests in Soil Conservation and Water Quality: Society vs. the Farmer, a paper for the American Agricultural Economics Association, Clemson University, July 27, 1981.

12. Crosson, Pierre. Environmental Consideration is Expanding Agricultural Production. Journal of Soil and Water Conservation 30, No. 1 (January-February 1975):23-28.

13. Crosson, Pierre and Brubaker, Sterling. Resource and Environmental Impacts of Agriculture in the United States. Washington, D.C.: Manuscript for Resources for the Future, Inc., December, 1980.

14. Edwards, William and Thompson, Harry. Estimated Costs of Crop Production In Iowa - 1981. Iowa Cooperative Extension Service Publication FM-1712, January 1981.

15. Felco Land O'Lakes. 1980 Chemical Crop Protection Guide. Minneapolis: Felco Corporation, 1978.

16. Fenton, T. E., Duncan, E. F., Shrader, W. D., and Dumenil, L.C. Productivity Levels of Some Iowa Soils. Iowa Cooperative Extension Service Report, No. 1 (1976):1-33.

17. Four Mile Creek Soil Survey. Mimeographed, Soil Research Laboratory. Iowa State University, Ames, Iowa 1981.

18. Frohberg, Klaus K. and Swanson, E. R. A Method for Determining the Optimum Rate of Soil Erosion. Agricultural Economics Research Report 161. Urbana: University of Illinois, April 1976.

19. Harmon, Lacy, Knutson, Russell, and Rosenberry, Paul. Soil Depletion Study Reference Report Southern Iowa Rivers Basin. U.S. Department of Agricultural, March 1979.

20. Heady, Earl O. Economics of Agricultural Production and Resource Use. New York: Prentice-Hall Inc., 1952.

21. Heady, Earl O. Some Fundamentals of Conservation Economics and Policy. Journal of Farm Economics, 32 (November 1950): 1182-1192.

22. Herfindahl, O. C. and Kneese, Allen V. Economic Theory of Natural Resources. Columbus, Ohio: Charles E. Merrill Publishing Co. for Resources for the Future, Inc., 1974.

23. Jensen, Harold. Farm Management and Production Economics. In A Survey of Agricultural Literature, Vol. 1, Chapter 7, Edited by Lee R. Martin. St. Paul: University of Minnesota Press, 1977.

24. Jennings, Vivian and Stockdale, Harold. Herbicide and Soil Insecticides Used In Iowa Corn and Soybean Production, 1977. Iowa Cooperation Extension Service Publication PM-845, 1978.

25. Kletke, Darrel D. Operation Manual for the Oklahoma State University Enterprise Budget Generator. Oklahoma Agriculture Experiment Station Research Report P-919, 1975.

26. Larson W. E. Protecting the Soil Resource Base. Journal of Soil Water Conservation, 36 (January-February 1981):13-16.

27. Lee, M. T. A Program to Estimate Net Return and Gross Erosion from a Watershed. Champaign: Illinois State Water Survey, 1976.

28. Lee, M. T., Narayanan, A. S., Gunterman, Karl, and Swanson, E. R. Economic Analysis of Erosion and Sedimentation, Hambaugh-Marginal Watershed. Agricultural Economic Research Report 127. Urbana: University of Illinois, July 1974.

29. Libbin, James D., Moorhead, Charles A., and Martin, Neil R. A User's Guide to the IBM MPSX Programming Package Part 1 - Small Models. Urbana: University of Illinois, 1973.

30. Lowdermilk, W. C. Conquest of the Land Through Seven Thousand Years, USDA, SCS Agricultural Information Bulletin 99, 1953.

31. McGrann, James M. Farm Level Economic Evaluation of Erosion Control. A paper for American Society of Agricultural Engineers, Chicago, December 18-20, 1978.

32. Miransowski, J. and Alt, K. Administrative Costs in the Theory of Externalities and the Selection of Nonpoint Pollution Policy. Journal of Economics, 4 (1978):159-162.

33. Miranowski, J. A., Monson, M. J., Shortle, J. S., and Zinser, L.D. Effect of Agricultural Land Use Practices on Stream Water Quality: Economic Analysis. Draft Final Report, Iowa State Cooperative Agreement, No. CR807087-01, 1981.

34. Narayanan, A. B. S., Lee, M. T., Gunterman, Karl, Seitz, W. D., and Swanson, E. R. Economic Analysis of Erosion and Sedimentation, Mendota West Fork Watershed. Research Report 126. Urbana: University of Illinois, April, 1974.

35. Narayanan, A. B. S. and Swanson, Earl R. Estimating Trade offs Between Sedimentation and Farm Income. Journal of Soil and Water Conservation, 27, No. 6 (November-December 1972):262-264.

36. Neill, L. L., Scrivner, C. L., and Keener M. E. Evaluating Soil Productivity Based on Root Growth and Water Depletion. University of Missouri - Columbia.

37. Nicholson, John T. Personal Communications, Soil Conservation Service, Toledo, Iowa, August 1980.

38. Nowak, Peter J. and Korsching, Peter F. Socialogical Factors in the Adoption and Maintenance of Best Management Practices. A paper presented at a Water Quality Goals Workshop, Iowa State University, Ames, Iowa, January 9-10, 1980.

39. Rausser, Gordon C. Economics of Soil Conservation From the Farmer's Perspective: Discussion, American Journal of Agricultural Economics, 62, No. 5 (December 1980):1093-1094.

40. Schaller, Frank W. and Ameyiya, Min. Conservation Methods and Procedures. Mimeographed. Department of Agronomy, Iowa State University, Ames, Iowa, 1977.

41. Seitz, W. C., Sands, M. B. and Spitze, R. G. F. Evaluation of Agricultural Policy Alternatives to Control Sedimentation. Research, No. 99, Water Research Center. Urbana-Champaign: University of Illinois, 1975.

42. Shulze, W. D. The Optimal Use of Non-Renewable Resources: The Theory of Extraction. Journal of Environmental Economics and Management, 1 (May 1974):53-73.

43. Shortle, James S. Soil Depletion and Water Quality: A Case Study in the Conjunctive Management of Natural Resources, Ph.D. dissertation, Library, Iowa State University, Ames, Iowa 1981.

44. Skidmore, E. L. and Woodruff, N. P. Wind Erosion Forces in the United States and their Use in Predicting Soil Loss. For U.S. Department of Agriculture in Cooperation with Kansas Agricultural Experimental Station, Washington, D.C.: U.S. Government Printing Office, 1968.

45. Smith, W. L. and Stamey, William L. Determining the Range of Tolerable Erosion. Soil Science, 100, No. 6 (1965):414-424.

46. Sposito, V. A. Linear and Nonlinear Programming. Ames: The Iowa State University Press, 1975.

47. Stamey, W. L. and Smith, R. M. A Conservation Definition of Erosion Tolerance. Soil Science, 97, No. 3 (March 1964):183-186.

48. Swanson, Earl R. Economic Evaluation of Soil Erosion: Productivity Losses and Off-Site Damages. Paper presented at the Economic Impact of Section 208 Planning on Agricultural, Pingree Park, Colorado, June 8-9, 1977.

49. Taylor, C. Robert and Frohberg, Klaus K. The Welfare Effects of Erosion Controls, Banning Pesticides and Limiting Fertilizer Application in the Corn Belt. American Journal of Agricultural Economics, 59, No. 1 (February 1977):25-36.

50. Troeh, Frederick R., Hobbs, J. Arthur, and Donahue, Roy L. Soil and Water Conservation for Productivity and Environmental Protection. Englewood Cliffs, N.J.: Prentice-Hall, 1980.

51. U.S. Department of Agriculture. The Draft and Environmental Impact Statement: A National Soil and Water Conservation Program. Washington, D.C.: U.S. Government Printing Office.

52. U.S. Department of Agriculture. 1977 National Resource Inventories. Mimeographed, 1978.

53. U.S. Department of Agriculture. Environmental Protection Agency. Control of Water Pollution from Cropland. Vol. 1. A manual for Guideline Development. Washington, D.C.: U.S. Government Printing Office, 1975.

54. U.S. Department of Agriculture. Forest Service. Soil Conservation Service. Economic Research. Iowa-Cedar Rivers Basin Study. Washington, D.C.: U.S. Government Printing Office, 1976.

55. U.S. Department of Agriculture. RCA Coordinating Committee. 1980 Appraisal Review Draft I. Washington, D.C.: U.S. Government Printing Office, 1980.

56. U.S. Department of Agriculture. Soil Conservation Service. Abundance or Scarcity: A Matter of Inches. Washington, D.C.: U.S. Government Printing Office, 1979.

57. U.S. Department of Agriculture. Soil Conservation Service. Economics, Statistics, and Cooperative Service. Soil Depletion Study. Reference Report Southern Iowa Rivers Basin. Washington, D.C.: U.S. Government Printing Office, 1980.

58. U.S. General Accounting Office. National Water Quality Goals Cannot be attained Without More Attention to Pollution from Diffuse or Nonpoint Sources. Report to Congress, Ced-78-6. Washington, D.C.: U.S. Government Printing Office, 1977.

59. U.S. General Accounting office. To Protect Tomorrows Food Supply, Soil Conservation Needs Priority Attention. Report Congress, Ced-78-6. Washington, D.C.: U.S. Government Printing Office, 1977.

60. Voss, Regis D. Guide to Efficient Fertilizer Use. Iowa Cooperative Extension Service Publication. PM-471-4, 1969.

61. Wade, James C. and Heady Earl O. National Model of Sediment and Water Qualities Various Impacts on American Agriculture. Iowa State University Center for Agriculture and Rural Development, CARD Report 67, July 1979.

62. Walker, D. J. An Economic Analysis of Alternative Environmental and Resource Policies for Controlling Soil Loss and Sedimentation from Agriculture. Ph.D. dissertation, Iowa State University, 1977.

63. Wischmeier, Walter H. and Smith, Dwight D. Predicting Rainfall - Erosion Losses from Cropland East of The Rocky Mountains. Agricultural Handbook, No. 282 (May 1968).